World-Wide Biostratigraphic Correlation
Based on Turritellid Phylogeny

BY

TAMIO KOTAKA

Institute of Geology and Paleontology. Tohoku University, Sendai, Japan

(7 Text figures)

INTRODUCTION

THE FAMILY TURRITELLIDAE includes several taxa that have generally restricted dispersal ability because of their very short veliger stage and ovoviviparity in some cases (LEBOUR, 1933; MARWICK, 1971; MERRIAM, 1941; PALMER, 1958, 1961; PEILE, 1922), therefore. genetically isolated groups must have diverged widely from each other during the course of Cretaceous and Tertiary time. In natural classification, this should be reflected by numerous localized genera and subgenera. According to MARWICK (1957), more than a thousand fossil and living species and subspecies of turritellas distributed in more than 40 genera and subgenera of 5 subfamilies are known from all over the world. Among 5 subfamilies of the Turritellidae, the Turritellinae is the largest and has a world wide distribution in time and space.

Even though their divergence is fairly wide, their shell morphology is, fortunately enough, very simple, and consists only of spiral cords or seldom spiral beads, and growth-lines on the shell surface, which can be traced back into the early stage of shell growth, the ontogeny of individual specimens.

Since L. GUILLAUME published "Essai sur la classification des turritelles, ainsi que sur leur evolution et leurs migrations, depuis le debut des temps tertiaires" in 1924, several monographic works on the Tertiary turritellas have appeared from several regions of the world. Most authors have tried to establish the phylogenetic trends of regional and/or local groups, for example, ALLISON & ADEGOKE (1960), BADEN-POWELL (1955), BOWLES (1939), IDA (1952), KOTAKA (1954, 1959, 1960), MARWICK (1957) and MERRIAM (1941) and others. Among these, the *Turritella (Neohaustator) saishuensis-andenensis* Bioseries of Japan established by KOTAKA (*op. cit.*), the *Zeacolpus (Stiracolpus) kaawaensis-delli* Bioseries (=Group *auct.*) in New Zealand by MARWICK (*op. cit.*), the *Turritella moodyi-cooperi* Bio-

series (= Stock *auct.*) of California by MERRIAM (*op. cit.*) and the *Turritella (Haustator) tricarinata-communis* Bioseries (= Series *auct.*) of Britain and the Mediterranean by BADEN-POWELL (*op. cit.*) are the most interesting to the writer from the viewpoint of biostratigraphic correlation mainly by means of respective turritellid bioseries.

Previously, the writer (KOTAKA, 1960) pointed out that there is fairly close similarity between each bioseries mentioned above, and concluded:

> ". . . the process of the transformation correspond to each other with high similarity, and can be designated as parallel evolution represented by the appearance and strengthening in the spiral sculpture, and if the age determinations settled by the respective authors are correct, the similar age of the beginning of the transformation in sculpture is recognized . . . it is noticeable that the complication in sculpture of these turritellid series took place during the late Pliocene and the early Pleistocene, a particular stage in the geological history."

Recent advances in precise biostratigraphic studies of the regions and paleontology of main taxa of the Cenozoic Era, for example, foraminifers, radiolarians, mollusks and diatoms, have called the writer's attention again to the turritellid bioseries of the late Cenozoic. And the writer here proposes to establish the world-wide biostratigraphic correlation and age determination of the late Cenozoic based on the turritellid bioseries.

BRIEF NOTE ON BIOSERIES

In order to facilitate the descriptions of change in spiral ornamentation from species to species in respective bioseries, the writer followed a system of notation previously proposed by MARWICK (1957) and emended by KOTAKA (1959: 59-60) as shown in Figure 1 and the following lines.

> "The first spiral generally appears as an angulation on about the adapical third of the whorl and sometimes this

Figure 1

Notation of spiral cord

spiral seems to make the protoconch merge into the first neanic whorls in several forms of the Japanese and New Zealand turritellas, this is designated primary spiral C. The one which appears on about the mid-whorl and the one abapical third of the whorl are designated B and A respectively. A and D are the peri-basal ones. The secondary spirals generally appear abapical to A, between A and B, between B and C, and adapical to C, these are denoted by the small letters r, s, t and u respectively. When the primary spirals become weak, the notation of the primary spirals A, B, C and D are changed into small letters a, b, c and d; when the secondary spirals rival the primary ones, then the secondary spirals, r, s, t and u are changed into capital letters R, S, T and U. Owing to the necessity the notation in the order of appearance of the spirals

can be combined. For example, the notation of the typical *Turritella saishuensis* Yokoyama is shown as $(C_1 B_2 s_4 A_3)$ and the typical *Zeacolpus kaawaensis* (Laws) as (u C B A r). Further, the tertiary spirals appearing in the interspaces between each preceding primary and secondary spirals are shown by a dot (.). If the tertiary spirals are so prominent that they must be noted, then the tertiary spiral appears abapical or adapical to the secondary spiral r is designated r_1 or r_2 respectively, one to secondary spiral s is s_1 or s_2, and so on. In some cases, the spiral threads or striae appear on the surface of preceding spiral A, they may be denoted Ä, and so on."

I. *Turritella (Neohaustator) saishuensis – andenensis* Bioseries

Among more than 60 fossil and living species and subspecies of turritellas known from the Japanese Islands and surrounding waters, *Turritella (Neohaustator) saishuensis* Yokoyama has the widest geographic distribution in the late Cenozoic of the Japan Sea borderland. Since Yokoyama described this species from the Pliocene deposits of Cheju Islands of Korea in 1923, the species has long been thought to be an important index fossil of the Pliocene, especially in the oil fields of the Japan Sea borderland, but subsequent authors (IDA, 1952; IKEBE, 1940; KOTAKA, 1954

Table 1

The regional and zonal variants in sculpture of *Turritella cooperi* Carpenter and related species

Species	Age	Notation	Merriam's Pl. & fig.
Turritella cooperi Carpenter	Recent	(u c b s a)	plt. 34, fig. 9.
		(. c . b . a .)	plt. 33, fig. 15.
		(C B A)	plt. 33, fig. 16.
		(C b A)	plt. 33, fig. 14.
	Timm's Point	(C b s a)	plt. 33, fig. 4.
		(C B A)	plt. 35, fig. 14.
		(d C A)	plt. 33, fig. 3.
	Santa Barbara	(C B A)	plt. 35, fig. 15.
		(c b A)	plt. 34, fig. 13.
Turritella margarita Nomland	Santa Margarita	(C . . A)	plt. 34, fig. 10.
Turritella carrisaensis Anderson and Martin	Santa Margarita	(C b A)	plt. 34, fig. 3.
		(C . A .)	plt. 34, fig. 2.
		(C A)	plt. 34, fig. 1.
		(. A)	plt. 34, fig. 5.
		(Smooth with shoulders at A and C)	plt. 34, fig. 6.
Turritella moodyi Applin (MS)	Temblor	(Smooth)	plt. 33, figs. 5-7.

and OTUKA, 1934) have split the species into subspecies and/or different species because of its fairly wide morphologic variation especially in spiral ornamentation. Based on the study of morphologic variation of the forms belonging to *Turritella (Neohaustator) saishuensis* (s. l.), KOTAKA (1954) summarized the phylogenic relationship between each form found in the Akita Oil Field.

The relationship of the different forms in the bioseries of *Turritella (Neohaustator) saishuensis* is shown in Figure 4 with the illustration of each typical form and the notation of spiral sculpture on the body-whorl.

The spiral sculpture of the adult *Turritella (Neohaustator) saishuensis* (s. s.) is represented by (C B s A), and this arrangement of the spirals is completed on about the ninth whorl. In some collection of *T. (N.) saishuensis* (s. l.) from the latest Miocene, most specimens are sculptured without the secondaries, these are named *T. (N.) saishuensis motidukii* Otuka. The forms with the notation (C B A) and the forms with other secondary and tertiary spirals are seldom found with the specimens of *T. (N.) saishuensis* (s. s.) in the early Pliocene, but these are very few in number statistically, for example, *T. (N.) saishuensis etigoensis* Ida in the middle part of the Pliocene deposits of certain oil fields of Akita and Niigata Prefectures. In *T. (N.) otukai* Kotaka, the ontogeny is more or less complicated, the spiral sculpture (C B s A) is completed on about the eighth whorl, and the secondary spirals r, t and u appear to occur in each position, and the typical *T. (N.) otukai* (u C T B S A r) is completed on about the 15th whorl, and further the fine tertiary spirals sometimes appear. Further, *T. (N.) otukai* evolved to *T. (N.) andenensis* Otuka, in this case, the ontogeny is more complicated and accelerated.

II. *Zeacolpus (Stiracolpus) kaawaensis – delli* Bioseries

MARWICK (1957) published a monographic work on New Zealand Turritellidae and the species of *Stiracolpus*, and presented a suggested relationship of *Stiracolpus* species and subspecies. He noted specific relationships (MARWICK, *op. cit.*: 24 - 25, 27). According to Marwick, even though slight changes in spire angle and whorl profile between each species exist, the intimate relationship between one another can be drawn as shown in Figure 6, mainly based on the ontogenetic development and similar order of appearance in spiral sculpture.

Concluding, Marwick's *kaawaensis-delli* Bioseries differentiated into several branches in Pliocene and Pleistocene time, and according to his descriptions and illustrations, these differentiations are clearly represented by the appearance and strengthening of the secondary and ter-

tiary spirals on each ancestral form so far as the surface ornamentation is concerned.

III. *Turritella moodyi – cooperi* Bioseries

Twelve stocks (= the bioseries of the present writer) of Cenozoic turritellas and a Cretaceous stock were proposed by C. W. MERRIAM (1941) from the Pacific coast of North America, based on close similarity of shell morphology with respect to   1) nuclear primary spiral rib component,   2) character of the growth-line trace, and   3) secondary factors such as whorl profile, apical and pleural angles, and size and nodosity. Among the 13 bioseries, the *Turritella cooperi* Stock of Merriam (= *Turritella moodyi-cooperi* Bioseries of the present writer) in the late Cenozoic (late Miocene to Recent) shows very similar progressive development to those of Japan and New Zealand so far as surface ornamentation is concerned. Figure 2 is
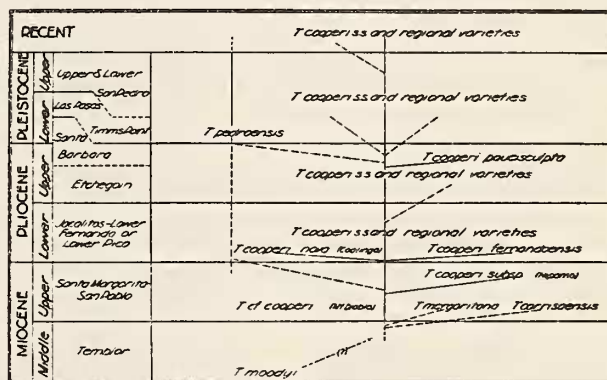

Figure 2

Stratigraphic distribution and suggested lines of evolution in the
Turritella moodyi – cooperi Bioseries
(reproduced from MERRIAM, 1941)

reproduced from MERRIAM (*op. cit.*: 49), and the following is MERRIAM's (*op. cit.*: 49) statement concerning the successive development of the Bioseries:

> "Throughout the long stratigraphic range of the species *T. cooperi* from uppermost Miocene to Recent, little successive change is observed. In nearly all assemblages characteristic regional and zonal variants are found, but certain individuals considered to be more or less typical of the species are found to range throughout, irrespective of stratigraphic or geographic position. In a given assemblage the specifically

typical forms may be present in limited numbers only, most individuals being regional or zonal types. It has been observed that, although a certain complex of variability may characterize the assemblage of a given locality, variants of this complex may occur in other horizons and regions sporadically."

The later half of the statement cited above contains a certain fundamental problem on the classification of fossil communities, and JOYSEY (1956: 85-86) has explicitly explained this problem as follows:

"When dealing with fossils from a geological succession we are faced with a more difficult problem, since it is a continuous series of intermediates. In most cases stratigraphic breaks provide convenient discontinuities, but in the case of a continuous record we are faced with the problem of subdivision for our own convenience. It is unavoidable that the position of the boundaries will be a matter for arbitrary choice, but it is relevant to discuss the direction in which the boundaries should be drawn, this being one of the main problems that the present symposium should endeavor to answer.

The two alternative systems of classification are illustrated in Fig. 1, in which the numbers 1 to 3 represent a series of geological horizons in ascending order. On horizon 1 the symbols *a, b* and *c* represent varieties within a single community in which the majority of individuals belong to the typical form "b" while "a" and "c" represent the less common extremes of variation. Similarly, at each horizon the middle letter represents the typical form, and the other symbols represent less usual varieties at this horizon. Ascending the succession, evolutionary change results in a progressive shift in the position of the mode of variation. We now have to decide the direction in which the series is to be subdivided. The boundaries may be defined either on a morphological basis, each of the species having a range, each of the species including the several varieties which formed part of the same community. The size of the categories is arbitrary, and so, for convenience in the following discussion, the two different types of species will be referred to as the variety and the chronological subspecies, respectively."

Careful study of the variants of *Turritella cooperi* (s. l.) (Carpenter) based on sufficient specimens collected from the stratigraphic sequence of the Pacific coast of North America will give us a basis of recognition for the chronological subspecies mentioned above.

Although MERRIAM (1941) did not describe the details of the regional and zonal variants of *Turritella cooperi* and related species, the variants in surface sculpture taken from Merriam's descriptions and illustrations have been tabulated (KOTAKA, 1960), and are reproduced here again. In Table 2 based on our collection of *T. cooperi* from the lower part of the San Pedro Formation of Deadman Island, California (IGPS coll. cat. no. 598) and Table 3 based on the specimens from the Palos Verdes Sand of San Pedro,

Table 2

Variation of the surface sculpture of *Turritella cooperi* Carpenter from the lower San Pedro Formation. (IGPS coll. cat. no. 598)

Notation	Number of Specimens
(C b A r)	1
(C B s . A)	2
(C . . A)	7
(C . A)	7
(C A)	3

Table 3

Variation of the surface sculpture of *Turritella cooperi* Carpenter from the Palos Verdes Sand. (USGS coll. cat. no. M2017)

Size of the last whorl in mm	Notation
more than 10	(C b . A r)
	(C b . A .)
	(C b A)
	(C . . . . A)
	(. . C B A)
5 - 10	(C . . . . A .)
	(C . . b . . A)
	(. . C A)
	(. C . . . . A . .)
	(. . . C . b . . A . .)
	(. . C . . . . A)
less than 5	(. . C b A)
	(C)
	(C . A)
	(C . A)

California (USGS coll. no. M2017) give us rather precise data on sculptural variation.

It seems to the writer very far from the structural study of a fossil community to draw an urgent conclusion from these tables, but they suggest a tendency of morphological variation of each species indicating a direction of development and even a trend of phylogenetic development of the bioseries in the way of domination and increase in the secondary spirals.

IV. *Turritella (Haustator) tricarinata – communis* Bioseries

M. Gignoux (1913) first pointed out the phylogenetic relationship between each form of the bioseries in the upper Cenozoic strata of the Mediterranean region, and Harmer (1914-1919) noted that each form belonging to this bioseries has a zonal significance in the British sequence. Then Baden-Powell (1954) applied the phylogenetic development of the bioseries to the British sequence and made an attempt to correlate the Pliocene and Pleistocene deposits between Britain and the Mediterranean region.

As shown in Figure 7, the bioseries of the Mediterranean and British forms are represented by the domination and strengthening of the secondary spirals.

According to Baden-Powell (1955: 278), the development in sculpture of this bioseries can be described in the following way:

> "Not only does the size of the shell increase from *T. tricarinata* to *T. communis,* but also the ornament of three spiral ridges seen in *T. tricarinata* acquires subordinate intermediate ribs in *T. communis* until they are as strong as the original primary ribs and make seven or more ribs of equal size. Gignoux also noted that the *tricarinata* and *pliorecens* forms of ornament can be recognized on the early whorl of the modern individuals of *T. communis*."

Bondi & Sandrucci's (1949) statistical analysis on the fossil community of *Turritella (Neohaustator) pliorecens* Monterosato (= *tricarinata* of Bondi and Sandrucci, 1949, *non. auct.*) collected from the Calabrian deposits of Italy also suggests the phylogenetic trend of the bioseries from *T. tricarinata* to *T. communis* through *T. pliorecens;* their statistics are given in Table 4.

Table 4

Variation of the surface sculpture of *Turritella (Haustator) pliorecens* Monterosata from the Calabrian deposits of Italy. (after Bondi & Sandrucci, 1949)

Class	Number of Specimens
3	8
4	10
5	46
6	132
7	139
8	156
9	95
10	35
11	16
12	14

In Table 4, the class represents the number of the whorl on which the first intercalary spirals or secondary spirals begin to appear, that is, according to Bondi and Sandrucci, the specimens included in the first three classes are allocated to the typical *Turritella communis,* and these of the last three to the typical *T. tricarinata.* Although they lumped up these forms into one species of *T. tricarinata,* and considered them to be of varieties because of their continuous change in sculpture, the writer believes that this community from the Calabrian should be allocated to the species of *T. pliorecens* according to the mode given by the frequency of morphological variations in the community, thus, the phylogenetic trend of the bioseries can be easily recognized from the viewpoint of population structure.

CONCLUDING REMARKS

All of these phylogenetic series or bioseries described above are exhibited by progressive increases in density and strength of secondary and tertiary spiral sculpture. This analogy seems to be a phenomenon of parallel evolution taking place contemporaneously in each regional or local bioseries.

And further, sudden and considerable change in sculpture in each bioseries is detected across the Pliocene-Pleistocene boundary shown as a broken line in Figure 3.

AGE		JAPAN	NEW ZEALAND	CALIFORNIA	ITALY
HOLOCENE			*delli*	*cooperi* (u c b s a)	*p.communis*
PLEISTOCENE		*andenensis*			
		otukai	*d.murdochi*		
		s.etigoensis (..C...B.s.A.r)	*d.vellai* (u C . B A r)	*cooperi* (C B A)	*pliorecens* (uCtB.s.Ar.)
PLIOCENE		*saishuensis*(s.s.) (C B s A)	*kaawaensis* (u C B A r)	*c.paucisculpta* (C b A)	*tricarinata* (u C . B A r)
				c.fernadoensis (c . . a)	
		s.motidukii (C B A)			
MIOCENE				*margaritana* (C . A)	
				carrisaensis (C A)	
				moodyi ( )	

Figure 3

Correlation table of 4 turritellid bioseries

At the present, although the physiological significance and mechanism of development in spiral ornamentations are not yet fully known, it can be emphasized that the world-wide decline of marine water temperature and/or shallowing of the marine realm caused by world-wide sea level change are reflected by sudden changes in sculpture, and this boundary roughly corresponds to the Neogene-Quaternary boundary when the world-wide ice-sheets started to develop.

In Italy, this boundary can be drawn between the Astian and Calabrian stages, that is, at the generally accepted Neogene-Quaternary boundary. In the New Zealand bio-series, this boundary corresponds to that of the Waitotaran and Nukumaruan Stages. And HORNIBROOK (1977) in summarizing the age determination of the New Zealand stages, put the Neogene-Quaternary boundary at the top of the Mangapanian Stage or the Waititaran Stage of old sense mainly by means of planktic foraminiferal ranges. His Neogene-Quaternary boundary is quite safely assigned to the boundary between the *Stiracolpus kaawaensis* and *S. delli vellai* zones in the stratotype sequence of the Waito-taran and Mukumaruan Stages along Wanganui Beach of North Island, New Zealand.

But placement of the Neogene-Quaternary boundary in Japan is still controversial; for example, IKEBE *et al.* (1977) put this boundary at the base of the Kitaura Formation correlative of the Tentokuji Formation in Figure 2, mainly based on a magnetostratigraphic event and the last occurrence of the planktic foraminifer *Globoquadrina asanoi*. At the same time, they noted that discrepancies still exist in age and correlation, especially with the scheme of molluscan biostratigraphers.

According to ADDICOTT (1977), the Neogene-Quaternary boundary in California has not been drawn strictly, but it seems to the writer that the boundary in question can still be drawn on at the base of the San Pedro Formation including the Timms Point Siltstone Member of recent sense as already shown by MERRIAM's text-figure (1941: 49, fig. 8) cited above.
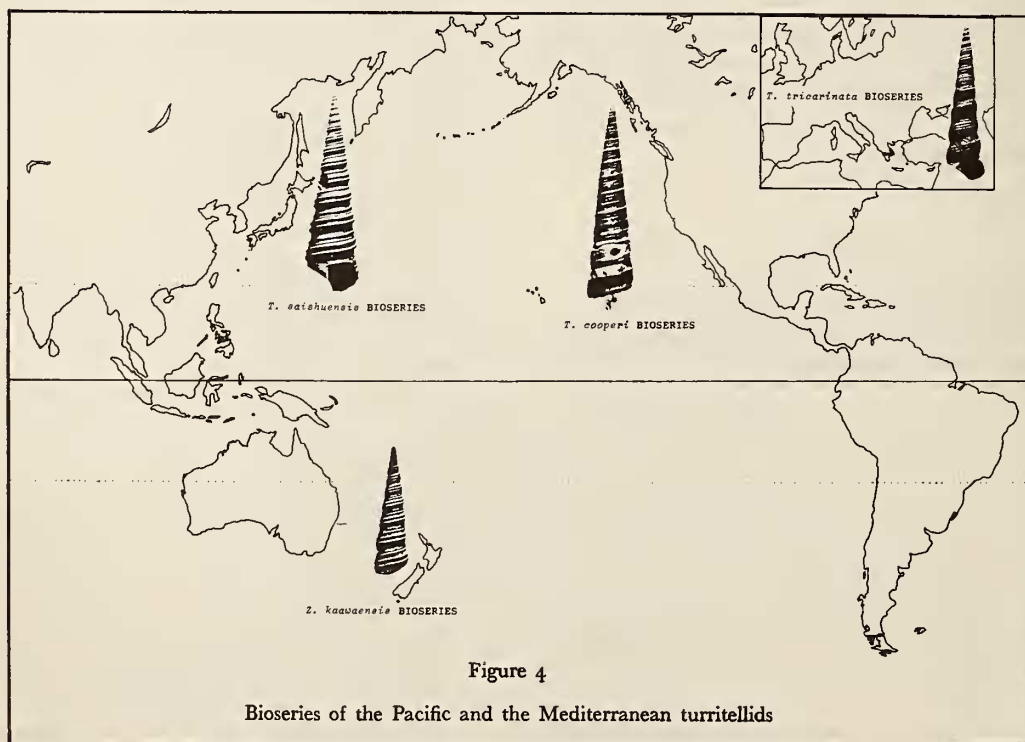
ACKNOWLEDGMENT

Figure 4

Bioseries of the Pacific and the Mediterranean turritellids
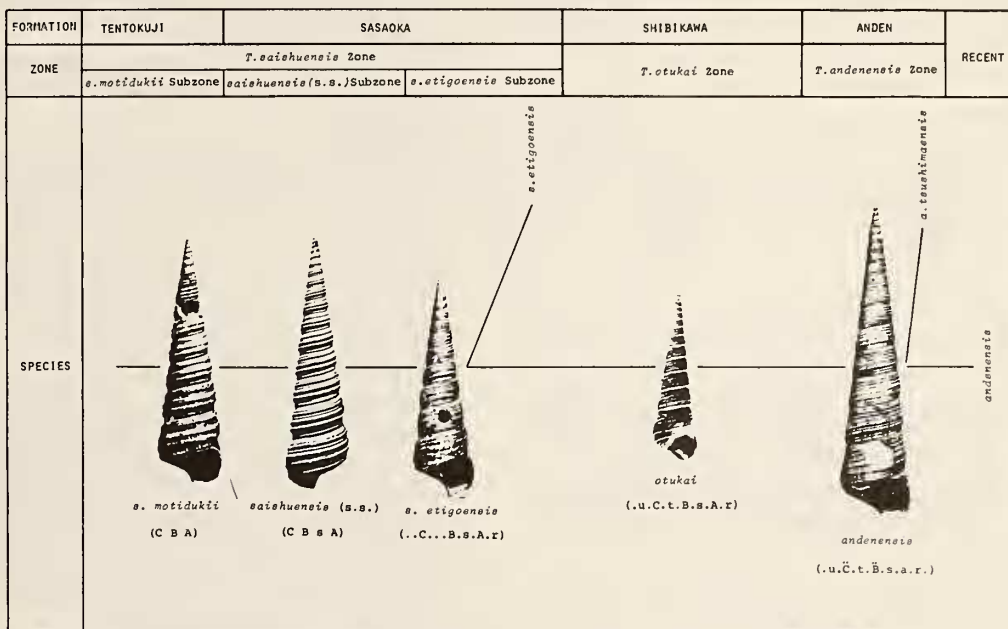
Figure 5

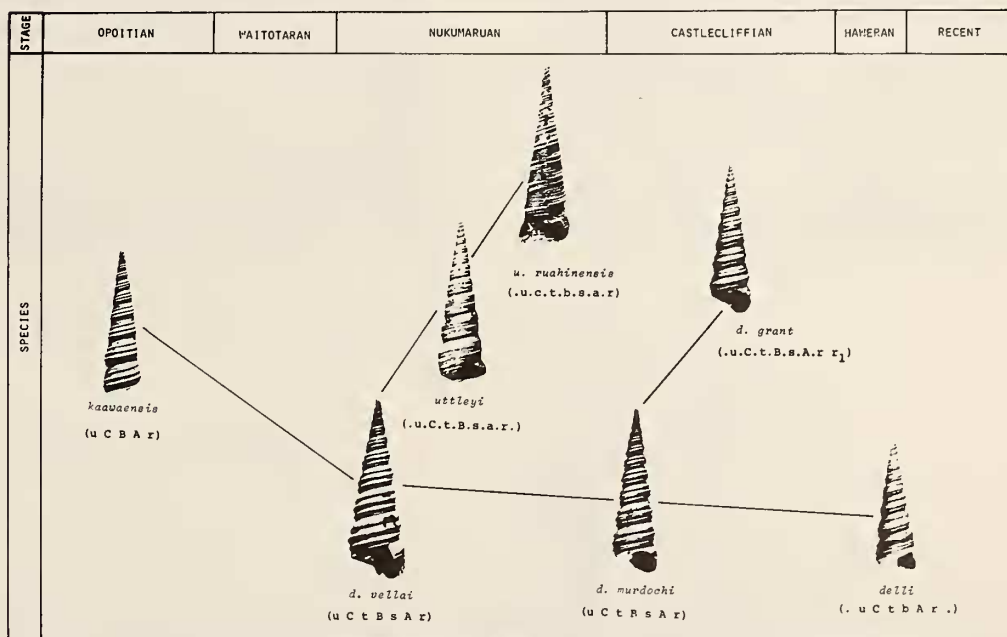Phylogeny of *Turritella (Neohaustator) saishuensis – andenensis*
Bioseries in Japan

Figure 6

Phylogeny of *Zeacolpus (Stiracolpus) kaawaensis – delli* Bioseries
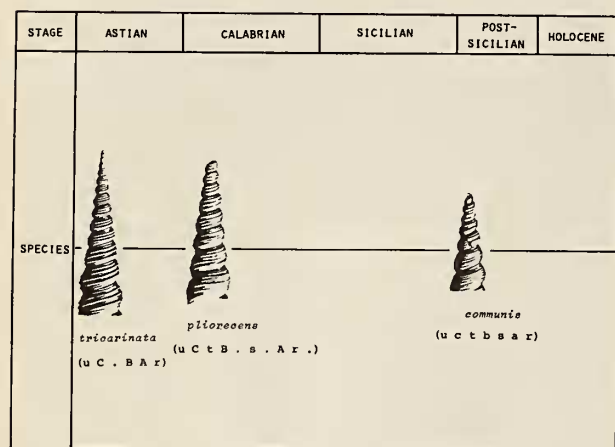in New Zealand

Figure 7

Phylogeny of *Turritella (Haustator) tricarinata – communis*
Bioseries in Italy

Literature Cited

ADDICOTT, WARREN OLIVER
1977.   Neogene chronostratigraphy of nearshore marine basins of the eastern North Pacific.   Proc. 1st Internat. Congr. Pacif. Neogene Stratigr., Tokyo, Japan, 1976: 151 - 175; 4 text figs.

ALLISON, RICHARD CASE & OLUWAFEYISOLA SYLVESTER ADEGOKE
1969.   The *Turritella rina* group (Gastropoda) and its relationship to *Torcula* Gray.   Journ. Paleont. 43 (5): 147 - 148; 2 text figs.

BADEN-POWELL, D. F. W.
1955.   The correlation of the Pliocene and Pleistocene marine beds of Britain and the Mediterranean.   Proc. Geol. Assoc. 66 (4): 271 - 292; 1 text fig.

BONDI, F. & L. SANDRUCCI
1949.   Su alcuni Molluschi plioceniti della Val d'Ere (Toscana) e su alcune anomalie de sviluppo.   Atti Soc. Toscana Sci. Nat. Mus., Ser. A, 56: 1 - 17; 1 table

BOWLES, EDGAR
1939.   Eocene and Paleocene Turritellidae of the Atlantic and Gulf coastal plain of North America.   Journ. Paleont. 13 (3): 267 - 336; 4 plts.

GUILLAUME, LOUIS
1925 (for 1924).   Essai sur la classification des turritelles, ainsi que sur leur évolution et leurs migrations, depuis le début des temps tertiaires.   Bull. Geol. Soc. France (4) 24: 281 - 311

HORNIBROOK, NORCOTT DE B.
1977.   The Neogene (Miocene-Pliocene) of New Zealand.   Proc. 1st Internat. Congr. Pacif. Neogene Stratigr. Tokyo, Japan 1976: 145 - 150; 2 text figs.

IDA, KAZUYOSHI
1952.   A study of fossil *Turritella* of Japan.   Rept. Geol. Surv. Japan, no. 150: 1 - 64; 7 plts.; 25 text figs.; 4 tables

IKEBE, NOBUO
1940.   On the stratigraphy of the Hatikoku and Oziya oil fields, Niigata Prefecture.   Journ. Japan. Assoc. Petrol Technol. 8 (5): 333 - 344 (in Japanese)

IKEBE, N. *et al.*
1977.   Summary of bio- and chronostratigraphy of the Japanese Neogene.   Proc. 1st Internat. Congr. Pacif. Neogene Stratigr., Tokyo, Japan, 1976: 93 - 113; 5 text figs.; 2 tables

KOTAKA, TAMIO
1954.   Ontogeny and phylogeny of some species of the genus *Turritella* from Akita oil field.   Seibutsu-Kagaku (Biol. Sci.), spec. vol., Evolution: 34 - 39; 4 text figs.; 2 tables (in Japanese)
1959.   The Cenozoic Turritellidae of Japan.   Sci. Rept. Tohoku Univ. (2) 31 (2): 1 - 135; 15 plts.; 10 text figs.; 7 charts; 3 tables
1960.   Similarity in the turritellid phylogeny in the late Cenozoic.   Sci. Rept. Tohoku Univ. (2) Special volume (4): 301 - 308; 4 text figs.

LEBOUR, MARIE V.
1933.   The eggs and larvae of *Turritella communis* and *Aporrhais pespelicani*.   Journ. Mar. Biol. Assoc. U. K., n. s. 18 (2): 499; 2 plts.

MARWICK, JOHN
1957.   New Zealand genera of Turritellidae, and the species of *Stiracolpus*.   New Zeal. Geol. Surv., Paleont. Bull. 27: 1 - 55; 5 plts.; 5 text figs.
1971.   Record of an ovoviviparous *Zeacolpus*.   New Zeal. Journ. Geol. & Geophys. 14 (1): 66 - 70

MERRIAM, CHARLES W.
1941.   Fossil turritellas from the Pacific Coast region of North America.   Univ. Calif. Publ:, Bull. Geol. Sci. 26 (1): 1 - 214; 41 plts.; 19 text figs.; 1 map   (8 March 1941)

OTUKA, YANOSUKE
1934.   Tertiary structures of the northwestern end of the Kitakami Mountainland, Iwate Prefecture, Japan.   Bull. Earthq. Res. Inst., Univ. Tokyo 12 (3): 566 - 638; plts. 44 - 51; 1 map

PALMER, KATHERINE EVANGELINE HILTON VAN WINKLE
1958.   Viviparous *Turritella pilsbryi* Gardner.   Journ. Paleont. 32 (1): 210 - 213
1961.   Additional note on ovoviviparous *Turritella*.   Journ. Paleont. 35 (3): 633

PEILE, A. J.
1922.   Note on reproduction of *Turritella*.   Proc. Malacol. Soc. London 15 (1): 13

YOKOYAMA, MATAJIRO
1923.   On some fossil shells from the Island of Saishu in the Straits of Tsushima.   Journ. Coll. Sci., Imp. Univ. Tokyo 49 (7): 1 - 9; 1 plt.